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## LIFE CYCLE COST – AN INTRODUCTION

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### Summary

"Life Cycle Cost" (LCC) calculations, which give the global cost for the complete life cycle of a system, are becoming most common in the aeronautical field.

Due to the actual budgetary context, characterised by stringent budget reductions, LCC is becoming a design parameter, having the same importance as the operational performance of the considered systems.

Cost-effectiveness analyses, combined analyses of total cost and operational effectiveness, are now often an integral part of the decision cycle, starting with the expression of an operational need and ending with a procurement order of the production aircraft.

Recent examples are the American Joint Strike Fighter (JSF) and the European Future Transport Aircraft (FTA).

LCC models are very well suited to make cost-effectiveness analyses. They generate the necessary data for the planning cycle, give a clear insight in the expense flows and guarantee a transparent cost structure.

There are a lot of different LCC models available. Some of them are predictive models, allowing weighing different design alternatives against each other. Others are models, allowing calculating the LCC of existing systems based on statistical exploitation data.

The experience of the Belgian Air Force using life cycle cost models is illustrated with two examples. These examples demonstrate that life cycle costing is a strong instrument assisting the logistic support manager, both on existing weapon systems and on weapon systems still to develop.

### Introduction

The need for *"design for low cost operation and support"* will be demonstrated, based on an example. This example is the acquisition of a future fighter aircraft.

A future fighter aircraft has to meet several stringent requirements in the fields of survivability, agility and manoeuvrability, capacity, performance, systems, avionics and sensors, weapons load and logistics.

It has to be survivable. Therefore it needs integrated self-defence systems and automated countermeasures, should have low observability, be fitted with NBC protection and be hardened against EMP.

It should possess agility and manoeuvrability. Vectored thrust is desired, giving the pilot the ability to look, to identify targets and to shoot in almost any direction. From the point of view of the aerodynamics, the airframe should be statically unstable, and the aircraft should have a high thrust-to-weight ratio.

The weapon system should be multirole: the aircraft should have fighter and air-to-ground capabilities.

In the performance domain, range and endurance should be high. Prolonged supersonic flights must be possible, the aircraft should have an excellent range and endurance, and be fitted with an air refueling capacity. Supersonic cruise should be possible.

The systems, avionics and sensors should be tremendously powerful. This is valid for the identification system, the electronic counter measures, the fire control system, the communication systems and the sensors. Moreover, all the systems and sensors should be integrated as much as possible.

Keywords for these systems are: security, reliability, interference-free, all-weather, ECCM, look-down and shoot-down, fire and forget, multiple engagements, detect and engage without radiating, ECM resistant communications, real-time distribution of voice and data, electro-optical and thermal imaging, sensor fusion, accessibility to GPS data, systems harmonisation and integration, beyond visual range, precision guided weaponry, internal weapon bays, ...

In the logistics field, robust, reliable, easily maintainable and easily deployable systems are desired. The logistic "footprint" should be small, and the systems, components and consumables should be standardised.

During the last decades, these requirements were met by systems with more and more complexity, and therefore a higher cost, especially in the field of the avionics. Further escalation of this cost, with the same growth rate, is not acceptable, especially when taking into account the today's budgetary context.

Most of the countries want to decrease the cost of defence. "Defence at any cost" is a thing of the past: the amount of money spent on defence is carefully weighed against the amount of money needed to tackle the other challenges of today's society.

Affordability is therefore becoming a critical issue. Looking at the United States, where the Joint Strike Fighter (JSF) is under development, the situation is straightforward: either the JSF will be "affordable", or the JSF will not come to full production.

The "capability/cost" balance is a real issue: all systems have to meet the operational requirements, but the operational requirements must not drive the systems' cost up to the point that the JSF becomes unaffordable.

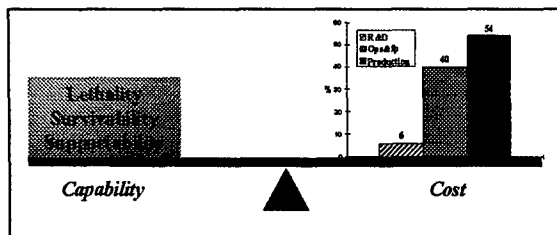


Figure 1: Cost-capability balance

Evident cost reduction solutions are to limit the quantity and the complexity of the next generation fighter aircraft. The real challenge however is to come to innovative designs, driven by cost and by operational effectiveness.

The "operations and support cost" will have to be tackled early in the design. Reliability, supportability, maintainability, and fleet management using prognostics and intelligent monitoring systems are to be considered.

To do so, modelling techniques are needed, allowing assessing the cost and operational effectiveness of the considered systems.

### Life cycle cost models

The notion of "life cycle cost" will be introduced and analysed. Its use in the different phases of the life of a weapon system will be shown. Through generic LCC-models, the link with Integrated Logistic Support (ILS) will be established.

### Life cycle cost

Affordability is a key issue for the acquisition of weapon systems, which are typically very complex systems, expensive both in acquisition and in operation and support. For those systems a trade off exists between the acquisition cost and the operation and support cost, as indicated in the figure below.

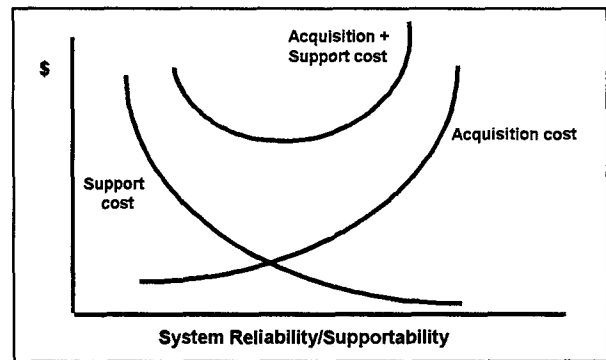


Figure 2: Trade-off between acquisition and support cost

The optimum solution has to be determined, based on the life cycle cost, the sum of all costs, estimated to be incurred in the anticipated life cycle of a weapon system.

Research and development costs, production and construction costs, operation and support costs and retirement and disposal costs constitute the LCC.

The nominal cost distribution of a typical Department of Defence program is indicated in the figure below.

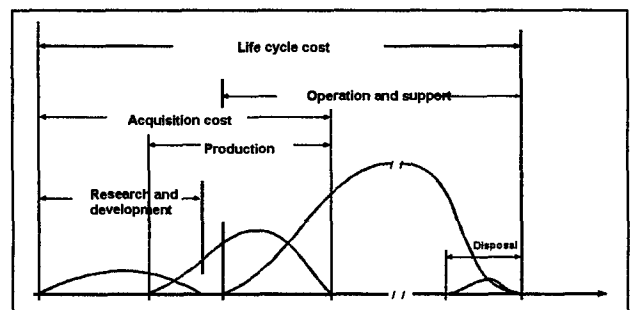


Figure 3: Nominal cost distribution of a typical DoD program

The life cycle cost commitment has a completely different profile. Early in the program, in the design phases, actual expenditures are low, but the decision-induced LCC are very high. It is in this phase that the design has to focus on low cost operation and support.

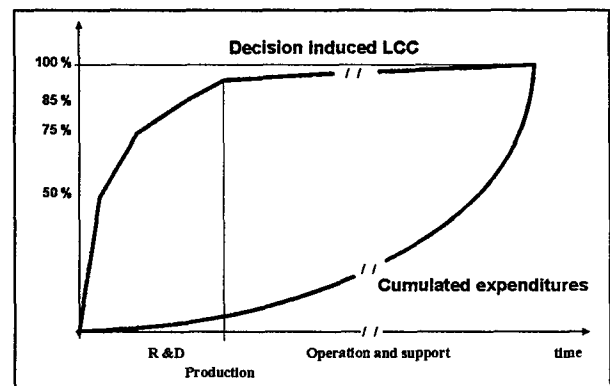


Figure 4: Life cycle cost commitment

## Role of LCC in the different program phases

To describe the role of LCC in different program phases, the research and development phase has to be split in three distinct phases: a conceptual design phase, a preliminary design phase and a detailed design phase.

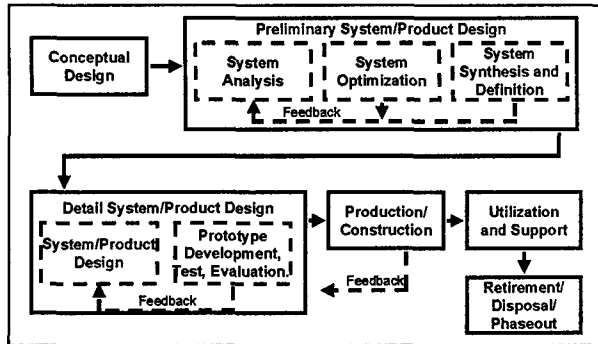


Figure 5: Role of LCC in the different program phases

During the conceptual design phase, a feasibility study will be made, system operational requirements will be written and the preliminary support concept will be outlined. The LCC model will have to generate budgeting figures and define key (cost driving) parameters.

During the preliminary design phase, a system optimisation and a system definition will be performed. This phase ends with a preliminary design, the analysis of a chosen configuration and the system definition (specifications and plans). The LCC model will have to predict and evaluate the LCC, based first on generic system characteristics and later on vendor data.

During the detailed design phase, a detailed design of the system, of the logistic support and the documentation will be performed. The design will also be reviewed. The LCC model will have to predict and evaluate the LCC based on vendor data.

During the detailed design phase, an engineering model, a prototype and the logistic support capability will also be developed, tested and evaluated. The LCC model will have to assess the LCC, based on test data.

During the production phase, the system will be produced and the initial logistic support fielded. The LCC model will collect cost data, analyse and report them. It will be used to assess the LCC based on production data.

During the system operation and support phase and the disposal phase, the LCC model will collect, analyse and report the cost data. It will be used to assess the LCC, based on field data and on disposal data.

Different LCC models thus are to be used. These models should have a structure, tailored to the program phase in which they are employed.

The input of the models, their output and cost resolution will vary throughout the program life, allowing the decision-makers to take the appropriate decisions in each program stage.

## Generic LCC models

Before paying attention to LCC models, it has to be stressed that LCC models have to be integrated in a global cost-effectiveness analysis, based on design attributes and logistic support elements, as indicated in the figure below.

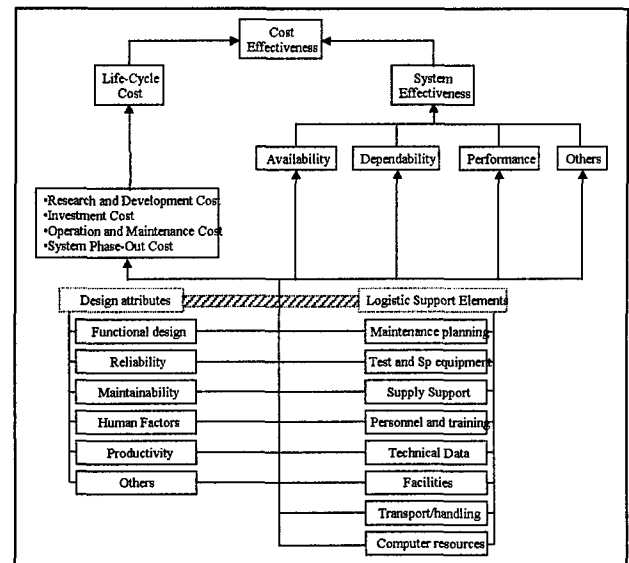


Figure 6: Cost-effectiveness analysis

In the United States, the United Kingdom (combined effectiveness and investment appraisal, COEIA) and the Netherlands, such a combined appraisal is mandatory for acquisition costs above a certain magnitude.

To be able to generate the LCC, a cost breakdown structure (CBS) has to be defined. To produce this CBS the events occurring during the life span of the system have to be identified.

Aggregating the cost estimates of these events (per year) will produce a "cost tree", modulated in time.

The aggregation of the costs, and the structure of the tree, depend on the purpose of the analysis and the program phase during which the LCC calculations are made.

A generic LCC model can be considered as a network of specialised models, generating all the costs mentioned in the cost breakdown structure and a calculator, producing the life cycle cost.

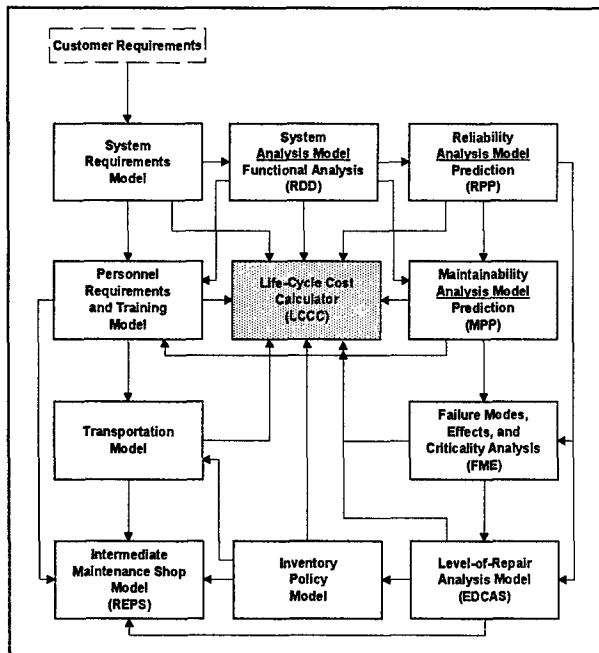


Figure 7: Generic life cycle cost model

There are a lot of specialised models, such as models calculating spare parts inventories, models determining the levels of repair, models predicting the reliability of the system components, ...

#### Cost estimation methods

To populate the cost breakdown structure, cost estimating methods have to be used.

There are two cost estimation methods: a predictive method, used before historical data are available, and a method based on statistical data, available for existing systems.

Predictive methods are based on different approaches.

The "parametric" method uses "cost estimating relationships", mathematical relations between the costs and physical or technical characteristics of the systems, to estimate the costs.

The method "by analogy" estimates the costs by using data, available for existing similar systems.

The method based on "the opinion of experts" generates costs by consulting experts, having experience with similar systems.

The "engineering" or "analytical" method generates costs using the cost of every component or activity. It uses a lot of design information and cannot be used early in the design.

Predictive methods will mainly be used in the design stages, while statistical methods primarily will be adopted during the operation and support phase.

#### LCC and Integrated Logistic Support (ILS)

ILS is a logistic function, with the following objectives: the integration of the logistic support in the design of weapon systems, the development of the specifications for the logistical support, the acquisition of the logistic support and the delivery of logistical support in the most cost-effective way.

ILS brings into the design, features such as reliability, maintainability and testability, which will be determining parameters for the operation and support cost.

The use of ILS allows the designers to search for the best compromise between performance, availability and life cycle cost of a weapon system.

#### Belgian Air Force experience with LCC

The BAF experience with LCC will be documented through two examples. In the first example, existing aircraft will be considered. In the second example, an aircraft in his early conception stage, the Future Transport Aircraft, will be discussed.

#### Belgian Air Force LCC experience with existing aircraft

The mission of the logistic support of the Belgian Air Force is clear: assuring the best technical condition and the flight safety of the aircraft, and guaranteeing the best technical condition of the other operational means.

To fulfil that mission, a global approach was defined and implemented. It was focused on the production of the best support of the operational units by the optimal use of the available resources.

The logistic management structures and the support structures were trimmed down and reorganised and an economic approach of the logistic support management was introduced.

Key to the reorganisation was the creation of business units at Airstaff level, responsible for all logistic aspects of a particular weapon system (combat aircraft, training aircraft, transport aircraft, ground radars, ...).

These business units, managed by "material managers" define and implement the support policies, necessary to realise the best technical content and the flight safety of the aircraft.

The support policies induce four categories of actions: routine maintenance, long term (structural) maintenance, "quality efforts" and the procurement of equipment through investment.

Routine maintenance is the basic maintenance, as defined by Belgian Airstaff, based on the recommendations of the aircraft constructor.

This maintenance constitutes the minimum level of activities to be performed on the aircraft. Its cost is the minimum budgetary level necessary to operate and support the weapon system. Belgian Air Force policy is to trim the routine maintenance expenses to the lowest level possible, without impairing the quality of routine maintenance.

Long term (structural) maintenance is the preventive maintenance needed to guarantee a good technical condition of the aircraft in the long term. It mostly consists of preventive replacements of structural parts of the aircraft. It is performed to alleviate the inspection workloads of the operational units and to boost the availability of the aircraft.

"Quality efforts" are maintenance actions performed to guarantee the best level of technical performance of the aircraft in the long term. They consist of (partial) system upgrades, beefing up the technical content of the considered systems to a state of the art level. They are performed to continuously operate, throughout the whole life cycle, supportable weapon systems, experiencing all the benefits of the best available technology.

Procurement actions are investment actions with the aim of adding more operational capacities to the aircraft or to replace them. They are funded by dedicated investment budgets.

Long term maintenance and quality efforts are, with the agreement of the Ministry of Finance, funded with "operations and support" money. They can only be performed with the results of the savings achieved in routine maintenance.

This stresses the importance of the "material managers" level. Their creativity to diminish the routine maintenance cost is stimulated by allowing them to explore ways to trim it even more, by creating and implementing long term maintenance and "quality efforts".

These dynamics work: a very substantial reduction of the routine maintenance expenses has been realised and our aircraft are continuously improved. On the C130 for example, the gas turbine compressor (GTC) was replaced by a modern auxiliary power unit (APU), the avionics are up-to-date and an On Board Oxygen Generating System (OBOGS) will be aboard from 2000 on.

To allow the material managers to obtain these results, it is obvious that financial analyses have to be performed. These analyses constitute the first BAF experience with life cycle cost models.

Because of the dedicated LCC structure, the analysis of the routine maintenance cost with LCC models allows the material manager to identify the major cost drivers and the most promising areas to explore in order to realise savings on routine maintenance costs.

LCC models are used to analyse the economic implication of long term maintenance or "quality efforts".

The material manager will calculate and compare the future costs of the logistic support of the system with and without the alterations considered. He will use statistical data, and will be able to perform a very straightforward economical analysis.

Based on this economical analysis, and taking into account supportability factors, a decision whether to proceed or not with the long-term maintenance plan or to the quality effort will be taken.

The BAF experience with a COEIA for the modification of existing aircraft is rather reduced, though a methodology to perform a COEIA was developed.

This methodology is aimed to provide the decision makers with a cost-effectiveness study, trading off all the possible options: no modification, change the utilisation or support policy, refurbish, upgrade, procure off the shelf, or develop and procure in different numbers.

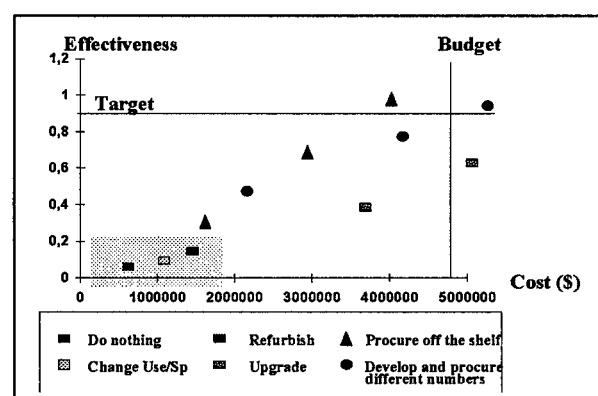


Figure 8: Cost-effectiveness for existing systems

### BAF LCC experience with the Future Transport Aircraft

Four European Nations, Belgium, France, Spain and the United Kingdom launched a competition to procure a "Future Transport Aircraft". The specifications for it were written down in a "European Staff Requirement" (ESR).

This ESR not only contains the typical specifications, such as the general and specific characteristics for the aircraft and the design standards, but also the Integrated Logistic Support requirements. The aircraft has obviously to be designed with "low cost operation and support" in mind.

The ILS part contains the general specifications for the ILS, specifications for the maintainability, servicing and testability and time limits. It specifies reliability, maintainability and testability demonstrations as well.

To appraise the different competitors, a joint concept of assessment was adopted by the nations.

The "Joint Concept of Assessment document" details the principles for the competition and describes how the participating nations intend to judge jointly the proposals for the FTA procurement:

*"The assessment will compare the cost-effectiveness, in whole life cycle cost terms, of defined fleets of candidate aircraft needed to deliver a prescribed level of transport capability in particular operational scenarios".*

Three candidate aircraft were in the running: the A400M proposed by Airbus, the C17 proposed by Boeing and the C130J-30 proposed by Lockheed Martin Aeronautical Systems (LMAS).

The criteria used for the comparison of the tenders are: the fleet cost estimates derived from the COEIA, the compliance with the ESR, the ability to meet the time constraints, a risk assessment, commercial aspects (terms, conditions and pricing) and industrial/economic aspects (offsets, share of work).

The COEIA was performed in a particular way: the LCC of a single A400M fleet was compared to (equivalent) fleets of C17/C130J with the same operational effectiveness. The equivalence between fleets was determined with nation-dependent operational scenarios.

Because of this construction, the comparison of the LCC of these operationally equivalent fleets immediately provides the COEIA.

The data necessary to calculate the LCC were agreed upon by the nations. They constitute a "Master Data & Assumptions List" (MDAL), and include: the LCC methodology (along with the cost breakdown structure), the government questionnaire, which comprises "harmonised data" and assumptions generated by the nations, and data from bidders, extracted from proposals. They are complemented by a support scenario/LCC analysis.

Several cost analyses were performed.

In a first stage, the support cost per aircraft was calculated to select preferred support scenarios in function of the fleet sizes considered.

In a second stage, the total cost per aircraft type was calculated to identify the main cost drivers for LCC and to identify the parameters subject to a sensitivity analysis.

In a third stage the LCC for equivalent fleets was calculated, for the different nation-particular operational scenarios.

In a fourth stage sensitivity analyses were performed, adding bands of uncertainty to the previous results. Retained parameters were the exchange rate, the unit-cost of the different aircraft and the maintenance cost.

Final result of all these calculations is a LCC comparison of the equivalent fleets, for each of the retained operational scenarios.

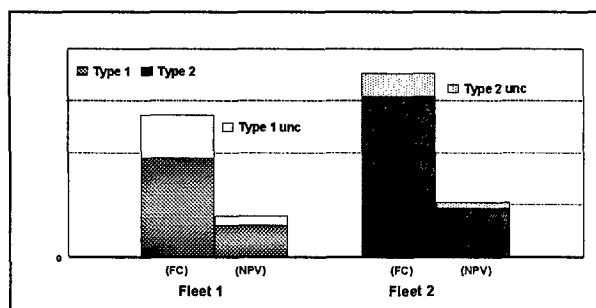


Figure 9: FTA cost-effectiveness

## Conclusion

To address the affordability of weapons systems, life cycle costing can be used.

Using this methodology has a lot of benefits: it forces long-range considerations instead of short-term thinking, it provides a total cost visibility, establishes clear relationships between the system elements and the elements of cost and causes a reduction in risk by identifying high risk areas.

Life cycle costing is applicable, both to new systems, by influencing design for lower life cycle cost and operation and support cost in particular, and to existing systems, where it can drive the search for continuous improvement leading to lower life cycle cost.

The adoption of integrated logistic support allows the designers to search for the best compromise between performance, availability and life cycle cost of a weapon system.

Life cycle costing proves to be a very powerful tool, allowing every logistic support manager to optimize his resources management.

## Acknowledgements

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